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The Use of Intermediate Inserts for CO_2 Laser Welding of Steel AISI 321 and a Grade 2 Titanium Alloy

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Abstract. The paper studies the structure, chemical and phase compositions, hardness and strength of welded joints obtained in AISI 321 steel and Grade 2 titanium alloy sheets by CO_2 continuous laser with the use of intermediate Cu, Ni and Ag-Cu-Zn alloy inserts. It is demonstrated that the maximum strength of welded joints is achieved by the welding conditions enabling one to form multiphase structures with intermetallics in the material of a weld, rather than only those based on solid solutions.

INTRODUCTION

Corrosion-resistant chromium-nickel steels and titanium alloys are known to be very poorly weldable. Extra difficulties arise when it becomes necessary to join structural components made of these heterogeneous materials, since there are considerable differences in their thermophysical properties. In this case, in order to obtain a strong joint, it is expedient to use intermediate plates to create a smooth transition from one material to the other when they melt and to reduce the probability of cracking in heat-affected zones [1 – 3]. The use of transition plates is particularly effective in laser welding, which, due to high rates of heating and cooling, forms narrow welds with small heat-affected zones. The aim of this study is to determine the microstructure, phase and chemical compositions of welds produced by laser welding of 3 mm thick sheets of the AISI 321 chromium-nickel steel and a titanium alloy through intermediate Cu, Ni and Ag-Cu-Zn alloy inserts.

MATERIALS AND RESEARCH METHODS

Three-mm thick sheets of steel (17.6 wt% Cr, 9.5 wt% Ni, 1.2 wt% Mn, 0.4 wt% Ti and 0.3 wt% Si) and a titanium alloy (99.5 wt% Ti) were welded by a continuous CO_2 laser in the Khristianovich Institute of Theoretical and Applied Mechanics, SO RAS (Novosibirsk). The radiation power was 1.7 kW and the speed of welding was 1 m/min, the ZnSe lens focus being located at a distance of 1 mm above the surface of the sheets to be joined. A mixture of carbon dioxide with air was used to protect the surface of the weld pool and the overheated heat-affected

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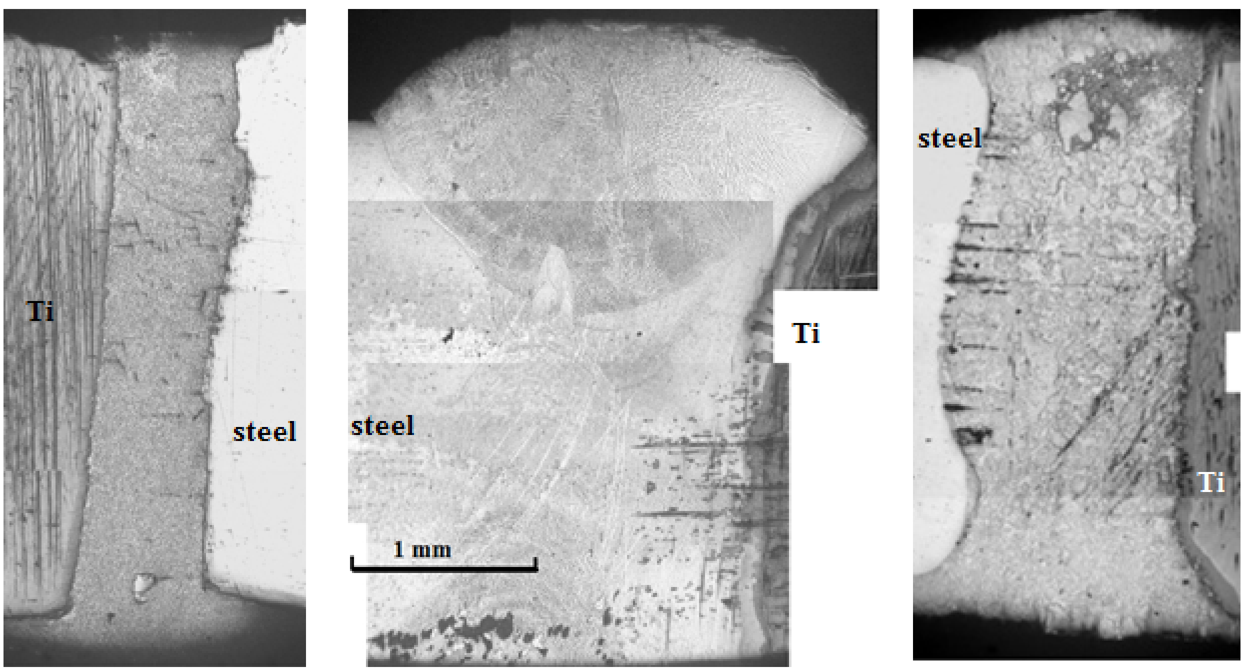
zones. The transition inserts were made of Cu (99.9 wt% Cu), Ni (99 wt% Ni) and the Ag-Cu-Zn alloy (65 wt% Ag, 20 wt% Cu and 15 wt% Zn). For all the specimens, the macro- and microstructures were analyzed and the pattern of microhardness distribution through the height and width of the welds was determined on a Leica device. The local chemical composition of the zones of the welded joints was determined on a Tescan Vega II XMU raster electron microscope with an Oxford energy dispersion accessory. The strength of the joints was determined from testing for static tension on an Instron 8801 machine, with a tension velocity of 1 mm/min.

RESULTS AND DISCUSSION

As an Ag-Cu-Zn alloy insert is used, with the focus positioned at a distance of 1 mm above the surface of the sheets, brazing is implemented, i.e. only the insert melts, whereas the materials to be joined melt only in a thin layer at the boundary with the braze, without participating in the formation of the welded joint. Ag-Cu-Zn alloys are known to be widely used as brazes, since triple eutectics 56Ag–24Zn–20Cu is formed in them at 665 ºC [4]. In the crystallization of the melt there occurs an eutectic L→α-Ag+α-Cu+p-Zn transformation, the crystallization rate being at least 600 ºC/min. The obtained joint is maximally homogeneous in the chemical composition and structure, fine and as narrow as 0.6 mm (Fig. 1a). It consists of a mechanical mixture of three solid solutions, Ag-, Cu- and Zn-based, their grains being at most 6 µm in size. The mean value of microhardness is 250 MPa, see Table 1.



(a) (b) (c)

FIGURE 1. The macrostructure of joints between the AISI 321 steel and a titanium alloy with inserts: Ag-Cu-Zn (a), Ni (b) and Cu (c)

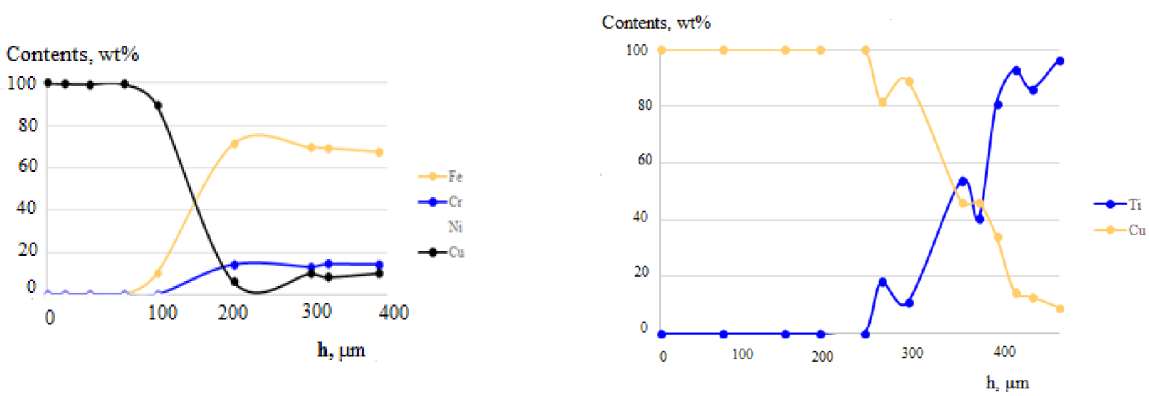
At the boundary with the titanium alloy there is a 20 µm thick diffuse zone, uniform through the specimen height, which is a solid solution of elements in titanium with a microhardness of 600 HV 0.05. In this zone there are disperse (at most 2 µm) TiAg particles. At the boundary with the steel the diffuse zone is discontinuous, its maximum thickness being 30 µm; it consists of a solid solution of copper, nickel, chromium, titanium and zinc in iron, with microhardness 550 HV 0.05. The obtained joint is fairly strong (σ_B = 289 MPa, see Table 1). The fracture surface of the tested specimens is characterized by fine dimple rupture, and it corresponds to ductile fracture, which is typical of ductile materials.

The use of a Ni insert with the same focus position results in the melting of the nickel insert, the alloys to be joined dissolve insignificantly in the weld pool to form transition diffusion zones at the weld boundary, and in the lower part of the joint there are multiple shrinkage micropores (Fig. 1b). The weld material is supersaturated solid solution of Fe, Cr and Ti in Ni. At the titanium alloy boundary, in the diffusion zone, there is precipitation of acicular Ti_2Ni and NiTi particles sized 5 to 20 µm, which increase the values of microhardness to 800 HV 0.05. The mean value of the microhardness of the welded joint is 300 HV 0.05, see Table 1. The minimum value 115 HV 0.05 is due to internal microporosity typical of cast alloys with a developed dendritic structure, which is observed when a Ni insert is used. At the boundary with the steel the microhardness values vary from 280 to 340 HV 0.05, and the material of the transition zone is a solid solution of Cr, Ni and Ti in γ-Fe. The strength of the joint with nickel is nit high (σ_B = 156 MPa, see Table 1), this being attributed to the dendritic structure and internal microporosity of the weld material. The fracture surfaces of the specimens after tension have a honeycomb relief typical of cast alloys.

TABLE 1. The width, strength (σ_B) and microhardness of the welds

Insert composition	**Weld width at ½ the height, mm**	**σ_B, MPa**	**HV 0.05**		
			max	**min**	**average**
Ag-Cu-Zn alloy insert	0.6	287	290	200	250
1.2 mm thick Ni insert	2.2	156	330	115	300
Cu 1 mm thick Cu insert (brazing)	1.0	152	125	109	120
1 mm thick Cu insert (welding)	1.2	385	580	220	315

The same laser welding conditions with the use of a copper insert have also enabled us to obtain a joint without any noticeable dissolution of the materials being joined in the weld pool, it is the copper insert alone that melts (brazing); at the steel boundary, in narrow transition zones (about 20 µm wide), iron, chromium and nickel contents gradually increase, with titanium content increasing at the titanium alloy boundary (Fig. 2). The strength of this joint is also low (σ_B = 152 MPa, see Table 1), this being due to the low strength of the copper alloy used.



(a) (b)

FIGURE 2. Distribution of the elements through the width of the joint with a Cu insert under conditions of brazing: at the steel boundary (a) and at the titanium alloy boundary (b)

A considerable increase in strength (σ_B = 385 MPa, see Table 1) is achieved when the focus is located 2 mm deeper in the sheets being welded and the radiation power is increased to 2.4 kW. Under these welding conditions, affected by a laser beam, weld penetration of the copper transition inserts and the materials being welded takes place, as well as their intensive diffusive mixing. This manifests itself in the penetration of titanium from the alloy through the insert material into the transition diffusion zone at the steel boundary, and the penetration of iron, nickel and chromium from the steel into the transition zone at the titanium alloy boundary. This results in the formation of a weld material based on the supersaturated solid solution of the alloying elements in the copper lattice and the particles of the $Ti(Fe,Cr)_2$ and $TiCu_3$ intermetallics sized 2 to 200 µm. The distribution of the elements through the width of the welded joint is nonuniform, and it corresponds to its phase composition (Fig. 3). Transition diffusion zones are formed at the interface between the material of the obtained weld and the alloys being joined. The macrostructure of the joint is shown in Fig. 1c. After tensile testing, specimen fracture (dimple rupture) occurs along the weld, the dimple rupture being characteristic of ductile fracture.

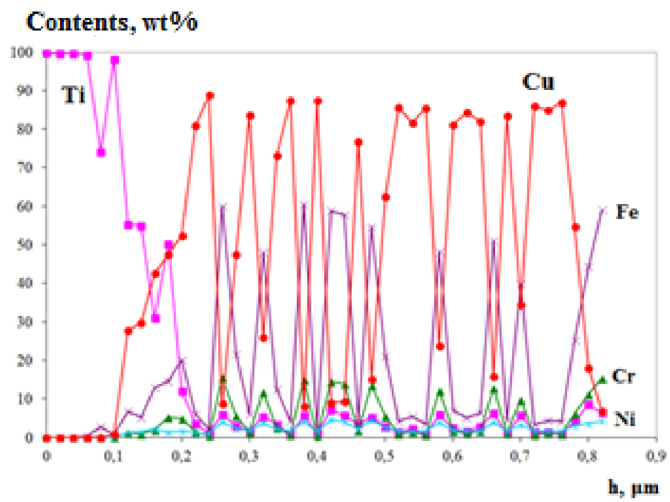


FIGURE 3. Distribution of the elements through the width of the weld with a copper insert

CONCLUSION

Laser-welded joints of the AISI 321 steel and the Grade 2 titanium alloy with Ag-Cu-Zn, Ni and Cu intermediate inserts have been studied. It has been found that the application of laser welding conditions when there occurs melting of only the intermediate inserts with the melting temperature below that of the materials being joined, the joint being formed by contact fusion of the steel and the titanium alloy along the eutectic transformations of zones with a limited thickness, enables one to form the material of joints based on solid solutions without intermetallic particles. The maximum strength is achieved when, with the use of an Ag-Cu-Zn alloy insert, a mechanical mixture of several solid solutions is formed through the L→α-Ag+α-Cu+p-Zn eutectic transformation.

The formation of intermetallics in a supersaturated copper-based solid solution under conditions of welding with the fusion of a 0.1 mm thick layer of the steel and the titanium alloy and their convective mixing in a weld pool offers a weld strength 2-3 times exceeding that of joints based on solid solutions alone.

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